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Spatial analysis of yield monitor data: case studies of on-farm trials and farm management decision making

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Abstract A 3-year case study was undertaken of how North American farmers use yield monitors for on-farm trials in farm management decision making. Case study methods were used because relatively few farmers quantitatively analyze yield monitor data. At this early research stage, insufficient farm management information about the data was available to ask the right questions in a large-scale survey. In addition to the formal case study of farmers experienced at using yield monitors to collect on-farm trial data, the study evaluated the effect of yield monitor data quality on farm decisions. Two levels of yield data quality included standard output where the default settings of farm-level mapping software were accepted and where filtering of the data was undertaken. Results indicated that yield data quality affects farm management decisions. In addition, farmers receiving a spatial analysis of their on-farm trial data tended to use split-field designs instead of replicated split-planter designs. They were also more confident in their decisions than before participation in the spatial analysis project, and made decisions more quickly.

Keywords On-farm testing · Spatial analysis · Decision-making · Yield monitor · Data quality

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Introduction

The commercialization of yield monitors with global positioning systems (GPS) has motivated innovative farmers to revisit the potential for collecting on-farm information to guide farm management decisions. Many US farmers conduct field-scale on-farm verifications of public sector extension and industry claims, and they fine-tune and test production systems (Urcola 2003). However, few do formal planned comparisons mainly due to additional time requirements (Urcola 2003). Some farmers have re-examined the usefulness of formal trials and quantitative yield data analysis because yield monitors lower the cost and effort of collecting data.

Classical statistics suggest that better inferences are made based on experiments that provide independent observations, such as familiar small-plot experiment station experiments. However, farmers continue to conduct field-scale on-farm experiments to test and verify systems under their environmental conditions even though the data collected are correlated as well as heterogeneous across space and inference would be considered invalid under classical statistics. Some farmers and researchers attempt to compensate for spatial variability by carrying out many replications of narrow treatment strips using field-scale experimental designs derived from classical small-plot statistics. Some farmers prefer to implement their planned on-farm comparisons in larger split-field and large treatment block experimental designs rather than strip-trial designs (Urcola 2003). Alternative field-scale experimental designs have been evaluated statistically (Griffin 2006).

Farmers commented on the difficulty of conducting on-farm trials. On-farm research logistical problems arise from difficulty in implementing experiments, farmer and analyst communication, data assimilation and interpretation (Lowenberg-DeBoer 2002; Griffin 2006). In addition to experimental designs, this case study examined spatial analysis services and farmer confidence in data and decisions.

Seven hypotheses were evaluated in this research (see Table 1):

- H1: farmers use a combination of qualitative information sources in making decisions,
- H2: farmers have more confidence in their on-farm trial based farm management decisions analyzed with spatial analysis techniques as compared to traditional non-spatial methods,
- H3: farmers who use yield monitors have dropped the use of other methods used to measure within-field yield,
- H4: printed yield maps have little value for farm management,
- H5: farmers prefer to make on-farm comparisons with strip-trial designs rather than large block split-field designs,
- H6: the timeliness of the availability of the results of the analysis is as important as its content,
- H7: the same farm management recommendations were made regardless of the yield data quality level.

Hypothesis 2 was explored only with the three experimental group farmers and Hypothesis 7 was tested for five individual field experiments conducted by experimental group farmers rather than the experimental and control cases.

This case study research builds upon earlier work on the use of yield monitors (Fountas et al. 2005; Urcola 2003). Urcola (2003) examined the decision-making process of ten Indiana, USA farmers and suggested that farmers with yield monitors placed more weight on on-farm trials than farmers not using yield monitors, partly because of increased ease of

Table 1 Hypothesis testing for individual case study farms

	Experimental group			Comparison group	
	D	F	W	P	T
H1: farmers use a combination of sources of qualitative information					
	NS	S	S	S	S
H2: farmers have more confidence with spatial analysis					
	S	S	S	NA	NA
H3: farmers using yield monitors have dropped other methods					
	S	NS	S	NS	S
H4: printed yield maps have little value for farm management					
	S	S	S	S	S
H5: farmers prefer split-field designs rather than strip-trial designs					
	NS	NS	NS	S	S
H6: the timeliness of analysis results are as important as content					
	NS	S	S	S	S

Hypothesis H7 relates to field studies rather than cases

S: hypothesis supported; NS: hypothesis not supported; NA: not applicable

collecting data. Fountas et al. (2005) analyzed data on perceptions of precision agriculture from a mail survey of farmers in Denmark and the US.

Methods

Case studies were developed to better understand farmers' use of planned on-farm trials using GPS yield monitors in their decision-making process and the potential value of spatial analysis. Spatial analysis is an inferential spatial statistical technique that explicitly accounts for spatial heterogeneity as well as the spatial interaction structure of neighboring observations. Spatial analysis techniques have been applied to site-specific yield monitor data before (Anselin et al. 2004; Griffin et al. 2005, 2006b; Lambert et al. 2004; Hurley et al. 2005). Three farmers conducted five field-scale on-farm trials and received spatial analysis reports. Project staff provided advice on designing the experiments, the results of spatial analyses and reports including farm management recommendations to the farmers belonging to the experimental group. As a point of reference, two farmers not receiving spatial analysis reports were interviewed. All five farmers were experienced in conducting on-farm trials but not all received a spatial analysis report prior to the final interview. Evidence were gathered on the three farmers receiving a spatial analysis report by casual observation over a 3-year period while formal interview data were collected from all five farmers at the project end. Because of the intense interaction with case study farmers only a relatively small number of cases could be completed.

Farmers' use of yield monitors and the value of yield monitor data quality were concurrently evaluated with case study and spatial statistical techniques, respectively. Case study methods were chosen because few farmers collect and analyze their yield monitor data and because, at this early research stage, insufficient information on the farm management uses of this data was available. The sample of cases is small. However, as Yin (2003) argued, increasing the size of the sample does not turn multiple cases into a generalized macro-scale study. He also indicated that single case studies are sufficient if the study meets the established objectives. Individual cases of this multiple case study were compared using the cross-case synthesis analytic technique with non-numeric interpretation (Yin 2003).

Partial budgeting methods (Boehlje and Eidman 1984) based on input generated with spatial econometric analysis techniques (Anselin 1988) were used to evaluate experiment treatments ultimately resulting in a production recommendation for the selected farmers. In this process, differing levels of yield monitor data quality were used as the dependent variable in the spatial statistical analyses. Typically, yield monitor data as recorded by the yield monitor (*original*) are subjected to ad hoc adjustment processes when imported into farm-level mapping software, such as SMS Advanced (AgLeader, Ames, Iowa, USA, http://sms.agleader.com/), JDOffice (Deere and Company, Moline, Illinois, USA, http://www.deere.com/), EASiSuite (MapShots, Cumming, Georgia, USA, http://www.mapshots.com/) or Farm Site (Farm Works, Hamilton, Indiana, USA, http://www.farmworks.com/). These adjustment processes correct for location, adjust yields according to moisture and remove observations outside of predetermined bounds (*default*). Alternatively, a conscious removal of erroneous data and relocation to appropriate positions (*filtered*) are possible with specialized software (Drummond 2006).

Data and analysis

Five on-farm experiments were analyzed with traditional non-spatial and advanced spatial analysis techniques using both levels of yield monitor data quality. Non-spatial refers to the traditional analysis in which location attributes, i.e., the spatial interaction structure of the observations, are not taken into account. During the 3-year project, the three farmers received advice from project staff on designing experiments and collecting data. Project staff conducted spatial statistical analyses of on-farm trials and provided reports to farmers. These reports comprised production farm management recommendations with details on the importance of considering spatial effects when analyzing yield monitor data (see Griffin (2006) for example reports provided to farmers).

During the analysis of spatial data, two levels of yield monitor data quality were evaluated by performing the analysis twice, once with each level of yield data quality. Yield quality levels include (1) accepting default settings from the farm-level mapping software (*default*) and (2) a conscious locational adjustment and removal of erroneously measured yield measurements (*filtered*). In order to create the filtered dataset, either *original* or *default* yield data were imported into USDA-ARS Yield Editor (Drummond 2006). Eleven filtering parameters were set to “optimal” values determined by trial and error, a priori information and analyst intuition (see Table 4 for details of the parameter settings). Production recommendations based on the most appropriate spatial analysis of *filtered* data were provided to the respective farmers. Case study data on farmer-subjects were collected during the spatial analysis and interview phases of this project. With the exception of Hypothesis 7, hypotheses were defined based upon a review of the literature with emphasis on Urcola (2003) and Fountas et al. (2005). The interview script was developed to evaluate Hypotheses 1 through 6 (see Griffin (2006) for the interview script).

Five farmers from Indiana, Illinois, Kentucky, USA and Ontario, Canada were interviewed at the end of this project. Farmers initially volunteered to collaborate with the authors primarily during announcements during the Top Farmer Crop Workshop at Purdue University (IN, USA). Farmers were selected based upon their expertise in conducting on-farm trials with yield monitors and were identified as innovators who sought out more appropriate analysis techniques. The resulting five case study farmers met the criteria of carrying out on-farm trials using yield monitors to gather data. The three farmers who received a spatial analysis report prior to the final case study interview volunteered for the project prior to the other two farmers and received reports in the second and third years of this project. Thus, case study subjects differed from representative farmers because they were closely associated with this research, performed on-farm trials and sought statistical analysis.

One farmer who received a spatial analysis report and both farmers who did not receive a report attended a Yield Monitor Data Analysis workshop (Erickson 2005; Nistor and Florax 2007). During the workshops, topics related to on-farm trials were discussed, including field-scale experimental designs, hands-on yield monitor data filtering and the importance of proper analysis of spatially auto-correlated data. In all, 30 individuals from four US states and Canada attended the workshops. The hypothesis regarding the benefit of consciously filtering yield monitor data relative to yield data processed by default parameters (Hypothesis 7) was evaluated as a result of suggestions made at the November 2005 workshop.

Case study evidence was gathered during all research phases. Project staff made multiple farm visits, analyzed on-farm trial data and provided spatial analysis reports to experimental group farmers over the 3-year project period. Researchers were granted access to events that were otherwise “inaccessible to scientific investigation” (Yin 2003, p. 94) and were able to view events internally (with experimental group farmers) rather than as an external viewer. In addition to casual observational evidence collected during the project, interview data concerning local production information from spatial analysis, experimental designs and the farmer’s decision-making process were gathered during the final interview.

Case study farmers

All three farmers receiving a spatial analysis report have at least 7 years experience mapping yields, and they continually test production practices on their farms. They agreed that yield monitor data influenced tiling and drainage decisions. At present, yield monitors are being used to fine-tune production systems. In addition, elevation data collected with GPS yield location were often used in on-farm trial analyses. Farmers were presented results based on spatial analysis of their on-farm trial data in the winter following the harvest of their respective experiments. Two farmers not receiving a spatial analysis report prior to the final interview were selected after hypotheses were defined and interview script developed in order to evaluate hypotheses across multiple case studies. They have been mapping yield for at least 13 years. With the exception of spatial analysis reports, these two farmers were not different from the other three farmers.

Farmer D

Farmer D produces irrigated corn (*Zea mays,* L.), soybean (*Glycine max* (L.) Merr.), popcorn, green bean (*Phaseolus vulgaris*, L.) and seed corn in Illinois. Illinois River bottom soils and variable topography influences yield response to inputs. Manual GPS lightbar navigation has been used for 5 years; however, no automated guidance has been used. Variable rates of lime, phosphorus, and potassium have been applied over the past 6 years. Farmer D has been using computers and the Internet for 11 years. He began collecting geo-referenced yield data in 2001. On-farm trials are a primary source of production information for Farmer D (see Table 2). Due to high quality criteria for popcorn, Farmer D evaluated yields and net returns from different combinations of seed applied fungicides and insecticides in 2004 (Field Experiment D1) based on contract popcorn production recommendations. With recent interest in Asian Soybean Rust, Farmer D and his local input suppliers tested two foliar applied fungicides as a plant health application against a control treatment in 2005 (Field Experiment D2) (see Table 3).

Farmer F

Farmer F grows corn and soybean under strip-till production in Indiana. Farmer F has been using computers for more than 12 years and the Internet for 10 years. Manual lightbar navigation was used for 4 years prior to adopting automated guidance 5 years ago. The highest level of GPS accuracy, RTK-GPS, has been used for automated guidance over the last 4 years and is currently used on four tractors. Yield mapping has been used for 8 years. Variable rate applications of lime, phosphorus and potassium have been used for 5 years. Based upon casual evidence from popular press articles that some farmers maintained soybean yields while lowering seeding rates along with increased soybean seed costs and the shift in soybean weed control practices, Farmer F evaluated the effects of reducing soybean seeding rates on yields and profitability in 2004 (Field Experiment F1) (see Table 3).

Farmer W

Farmer W produces corn and soybean in Kentucky. The farm is situated in rolling hills with eroded hilltops and depression areas prone to reduced yields in wet years. Farmer W has been practicing no-till production for over 20 years; however, many fields were extensively tilled prior to Farmer W's management practices. Lightbar navigation has been used for 10 years and automated guidance for three. The Internet and email have been used for the last 5 years. Farmer W has been yield mapping for 12 years. Due to changes in local sales representatives, Farmer W evaluated corn hybrids to determine yield and profitability (Field Experiments W1 and W2) (see Table 3).

Farmer P

Farmer P produces corn, soybean, and soft red winter wheat (*Triticum aestivum,* L.) in Kentucky. Farmer P has been mapping yields for 13 years, using computers for farm management for 28 years and the Internet over the past ten. Manual lightbar navigation was used 5 years ago and automated guidance was used on equipment for the last 3 years. Variable rates of lime and seeds have been used for 9 and 11 years, respectively. On-farm trials have been a management practice for 10 years to evaluate if ideas are sustainable (see Table 2). Farmer P evaluated phosphorus application on wheat.

Farmer T

Farmer T farms corn, soybean, dry edible bean (*Phaseolus vulgaris*, L.) and durum wheat (*Triticum durum*, Desf.) in Southwest Ontario, Canada. The farmer was considered to be an innovator with the first automated boom sprayer in Ontario, and has been mapping

Table 2 Response to selected questions on yield maps, on-farm trials, and advice for other farmers

Experimental group				Comparison group	
Question	D	F	W	P	T
What is the value in printed yield maps?	Better than watching yield monitor numbers from the combine, just pictures	None if have good sized computer monitor. Maybe take to landlord to discuss improvements.	Remind of costs and returns on marginal land	Identify areas needing more management	No need for paper yield map. Value in maps on the computer screen
How do on-farm trials fit in as part of your production information?	Primary data for decision-making	Small tests prompted to begin strip-till system and use RTK automated-guidance	Verifies intuition	With a careful conservative approach. Continue to evaluate proven sustainable ideas.	Add to information base. After 2 years of promising data, do a third year and maybe implement on fourth year.
What advice would you have for farmers considering on-farm trials for the first time?	Be careful with data, yield monitor calibration is important. Tend to little details	Make sure have enough time to do trials and devote enough time to trials	Consult extension researchers for guidance on experimental designs	Be prepared for extra time commitment, be patient and do not be in a hurry; garbage in garbage out	Start slow. Do not expect too much. Precision agriculture and yield monitors are tools with limitations. Bounce ideas off someone with experience.
What advice would you have for farmers experienced with on-farm trials?	Share information	Plan the trial before going to field. Work with everyone involved, e.g. make sure analyst approves experiment	Have yield monitor data actually analyzed.	Implement result on small or medium scale if large enough gain and if good design, valid, and proven.	Limit number of variables. If compare varieties, do not look at populations. Be consistent, standardize what you can. Replicate if possible. Do "what-if" analysis such as weather

Table 3 Summary of field studies similarities

Field experiment		D1	D2	F1	W1	W2
Crop and year		2004 popcorn	2005 soybean	2004 soybean	2004 corn	2004 corn
Experimental design		Pseudo-replicated	Strip-trial	Strip-trial	Split-field	Split-planter
Treatment tested		Seed applied insecticide and fungicide	Plant health foliar fungicide	Seeding rates	Hybrid	Hybrid
Region		Illinois	Illinois	Indiana	Kentucky	Kentucky
Format data acquired		*Default*	*Default*	*Raw*	*Raw*	*Raw*
Number of observations		3.227	2.650	3.897	19.404	4.798
Type of study[a]		C	C	R	C	C
Replication		No	No	Yes	No	Yes
IDW distance band (m)		64.9	45.1	25.0	25.0	54.9
Recommendation changed from appropriate spatial analysis with wider spatial interaction structure?[b]	Non-spatial	Yes	Yes	Yes	No	No
	"Shallow" interaction structure[c]	Yes	No	No	No	No
	Default	No	No	No	No	No
Usable results with non-spatial analysis?		No	No	No	Yes	Yes

[a] C—categorical, R—rate trial

[b] The more computationally intense spatial interaction structure

[c] Shallow is the less computationally intense spatial interaction structure, minimum Euclidean distance

yields for 14 years. Manual lightbar navigation has been used for 5 years and automated guidance for 3 years. Variable rates of nitrogen, phosphorus and potassium fertilizer have been used for 9 years. He began using computers and the Internet extensively 18 years ago. Farmer T evaluated nitrogen rates on corn.

Results

Besides using yield monitors and conducting on-farm trials, all subjects had at least a first university degree and maintained strong relationships with public sector university outreach and extension, attesting to their analytical disposition and commitment to life-long learning, especially about their farms. One common element was that farmer operations were geographically dispersed from one another across four US states and Canada. All farms have computers and use email. None of the farmers from either group used yield monitors for farmland leasing arrangements, negotiations or crop shares.

On-farm trials and yield monitors

Farmer D used on-farm trials and yield monitor data as the primary source of quantitative information while the other four farmers used their on-farm trial data as a major source of production information along with suggestions of advisors (see Table 2). Urcola's (2003) groups differed from each other by the relevance of on-farm trials in their farm management decision-making process. Four out of five farmers with yield monitors from Urcola (2003) used on-farm trials as the primary source of quantitative information for selecting hybrids and varieties. Based on this case study research, Hypothesis 1 that farmers use a combination of qualitative information sources in making decisions was supported by four out of five cases (see Table 1).

All three farmers receiving a spatial analysis report stated that their confidence in on-farm trials and subsequent farm management decisions increased relative to the situation prior to using spatial analysis. Farmers D and W were more confident about answers and data from experiments, which Farmer D felt was very important. Farmer F had increased confidence in on-farm trials after earlier failures. Farmer D was more likely to take action, make decisions faster and make more decisions than before using spatial analysis techniques. Farmer W now thinks differently about on-farm trials and is always considering what other factors to test. Increased confidence may have been the result of their questioning applicability of traditional analysis and seeking out appropriate analysis in the form of spatial analysis. In addition, spatial analysis results were often in agreement with the farmers' intuition regarding their treatment effects. Since several farmers expressed interest in learning to conduct their own spatial analysis, it logically follows that spatial analysis itself was pertinent rather than experts performing the analysis. Therefore, Hypothesis 2 that farmers have more confidence in their on-farm trial-based farm management decisions analyzed with spatial analysis techniques as compared to traditional non-spatial methods was supported.

Some farmers have dropped the use of other forms of yield measurement (e.g., weigh wagons) in favor of yield monitors to collect on-farm trial data. Farmer P stated that weigh wagons would be used until yield monitors became more reliable. Farmer F experienced repeated mechanical failures in one brand of yield monitor equipment before switching to another, and remains cautious of the technology. Three out of five of Urcola's (2003) farmers used yield monitors as the sole within-field yield measurement tool, i.e., they stopped the use of weigh scales for each treatment, which supports the findings of this research. Hypothesis 3 that farmers who use yield monitors have dropped the use of other methods used to measure within field yield was supported for three out of five farmers (see Table 1).

Forty-two percent of the Fountas et al. (2005) survey participants who had been using precision agriculture for more than 5 years stated that yield maps were very useful. However, the percentage dropped to 10% for farmers with less than 5 years of yield maps. Re-affirming Urcola's (2003) assertion that subjective visual observation was the most common method to analyze yield monitor data, Fountas et al. (2005) reported that more than 75% of farmer respondents printed yield maps. Urcola (2003) found that only two out of five case study farmers were satisfied with yield map information. This is in agreement with case study farmers who said printed yield maps had little value, especially after they learned that spatial analysis could be conducted statistically (see Table 2). Therefore Hypothesis 4 that printed yield maps have little value for farm management was supported.

Experimental designs

Farmers prefer experimental designs that provide data suitable for making farm management decisions, and which are easy to plan, implement and harvest. Each experimental design offers specific advantages and disadvantages that differ by treatment, farmer, equipment configuration and management practice. Farmer D wanted experimental designs requiring less time but at the same time providing reliable, reproducible data. Farmer W stated that if experimental designs increased time requirements that would be like "going backwards."

All five farmers were critical of the small-plot and strip-trial designs frequently implemented in a classical statistical context. Farmers stated that they do not use small-plot designs because of excessive time requirements, results not being representative of field-scale conditions, or excessive cost. Farmers D and T stated that split-planter trials do not always work well for their equipment set configurations. Farmer F was concerned about treatment edge effects and application drift masking true treatment differences. Farmer P stated that split-planter trials are difficult to analyze if not mapped properly.

All five farmers acknowledge that many of the problems associated with small-plot or strip-trial designs are eliminated with split-field or larger block designs. For instance, instead of cleaning planter boxes or filling half of planter boxes with certain varieties or other treatments, planter boxes are filled with the same product and then treatments are changed during normal reloading times. Large block designs require minimal additional effort during planting or harvesting. Large experimental units also offer the advantage of being less sensitive to human and mechanical error or treatment edge effects, including differences in row spacing on adjacent planter passes. Experimental group farmers preferred designs that were more likely to be completed, required minimal effort, and minimized chance of making errors from implementation to harvesting.

Although split-field large treatment block designs are becoming more acceptable to farmers and their advisors, these designs are not perfect. Farmer W stated that with split-field trials it is "more difficult to compare apples to apples" and some replication is usually needed to collect ample yield monitor data from each treatment-zone combination. Urcola's (2003) case study farmers using strip-trial designs cited the spatial variability of yields in split-field designs as the primary disadvantage.

There were differences between farmers who received and did not receive a spatial analysis report with respect to preferred experimental designs. All three farmers receiving a spatial analysis report were similar to Urcola's (2003) farmers in that they reduced the proportion of experiments in split-planter strip-trial designs in favor of split-field designs. Six out of ten of Urcola's (2003) farmers wanted to compare hybrids in large split-field blocks rather than strip-trial designs. Although farmers felt confident about their split-field design data after receiving spatial analysis reports of their on-farm trials, the two farmers not receiving a spatial analysis report preferred the numerous replications of split-planter designs to isolate as much variability as possible. Farmer P attended the November 2005 Yield Monitor Data Analysis workshop and Farmer T attended both workshops, so it is not suspected that researcher involvement biased their perspectives. One supposition for differences between farmers include those receiving a spatial analysis report perceived data as credible that was formally perceived as convoluted. However, farmers not receiving a spatial analysis report recognized the potential in-field problems that arise from machinery issues and agronomic interaction influencing treatment effects as well as the barriers to analyzing data gathered from strip trial designs. Therefore, Hypothesis 5 that farmers prefer to make on-farm comparisons with strip-trial designs rather than large block split-field designs was not supported for Farmers D, F, and W, and supported for Farmers P and T.

Spatial analysis service

Farmer perceptions of spatial analysis results, the reports and services associated with the analysis were evaluated to identify ways that the agricultural industry and/or public sector extension programs could make these services more attractive to farmers. Farmer T made the distinction between consultants and experts. Consultants may have been associated with sales representatives of unproven products whereas experts are specialists with scientific qualifications. In the Fountas et al. (2005) survey, the public sector university personnel were referred to as "specialists" with expertise, and the private sector personnel were referred to as "agricultural consultants." Case study evidence suggests farmers are sceptical of sales personnel and would rather deal with experts possessing technical skills.

The farmers not receiving a spatial analysis report provided insightful and useful feedback on the ideal spatial analysis service although the perceived criteria differed from farmers receiving a spatial analysis report. Farmers receiving a spatial analysis report desired assistance with: (1) experimental design, (2) prescription for inputs, (3) yield monitor calibration, (4) interpretation and (5) decision making. Farmer T suggested soil test and analysis were a part of the spatial analysis service, including a farm visit after on-farm trial implementation to discuss the planned and actual experiment. Farmer T went on to suggest that yield data be sent to a spatial analysis laboratory and farmers receive a two-page report including economic analysis. Fountas et al. (2005) stated that US farmers requested that an analysis service: (1) support the use of gathered data, (2) provide economic analysis and (3) provide variable rate applications.

Case study farmers suggested that farmers may also prefer to conduct their own spatial analysis. If outsourced, the service could be offered by a private firm or public sector extension. Four of the five case study farmers suggested they themselves may eventually provide service to other farmers especially if their skill level, interest and time were sufficient.

Farmers receiving a spatial analysis report requested additional assistance with interpreting analysis results. Three of Urcola's (2003) farmers stated that basing farm management decisions on yield maps was confusing and difficult. Although Fountas et al. (2005) reported that the most requested information by Denmark farmer-respondents was yield map interpretation, US counterparts did not make similar requests. In the Fountas et al. (2005) survey, 22% and 10% of US farmer-respondents stated that yield maps and soil maps, respectively, were difficult to interpret with roughly one-fourth stating that both were very easy to interpret. Fountas et al. (2005) added that 69% of farmers felt data handling took too long. All five case study farmers requested economic analysis. Farmer F stated that the final answer is all that is needed. Farmer W stated timeliness was as important as content (see Table 2). Although Farmers F, P and T agreed with Farmer W about the importance of timely results, Farmer D valued any information available about his farm. This may have been because of the lack of public sector involvement in his relatively isolated production region compared to other case study farmers. Hypothesis 6 that timeliness of the availability of the results of the analysis is as important as its content was supported for four out of five farmers.

In addition to the above farmer statements on data analysis services, it was interesting to observe what was not stated by the farmers. Local agronomic knowledge of the service was not mentioned. Since case study subjects agreed that the service could be centrally located anywhere in the world, they did apparently not perceive local knowledge to be crucial to the service or that spatial analysis results would be one of several sources of information next to, for instance, recommendations based on local expertise.

Yield data quality

Five on-farm trials were analyzed using non-spatial and two spatial analysis techniques. Two levels of yield monitor data quality were compared for five on-farm trials. The basic quality of yield data was processed using the default parameter settings of the farm-level mapping software. The higher quality level of yield data was consciously filtered by imposing field-specific bounds (see Table 4 for filtering parameter details), and adjusting location attributes with USDA-ARS Yield Editor (Drummond 2006) as described in Griffin (2006). In two out of the five trials, the same farm management recommendation would have been made with either level of yield data quality for both non-spatial and spatial analysis (see Table 3). In the remaining experiments, differences in farm management recommendations would have occurred between spatial and non-spatial analyses when yield data quality differed.

When spatial analysis is based on a spatial interaction structure where neighboring grid cells within a pre-specified cut-off distance such that each observation has at least one neighbor (minimum Euclidean distance) is used, different farm management recommendations between yield data quality levels were made for all but two field experiments. When the spatial analysis was conducted using a wider spatial range for the interaction (i.e., substantially more neighbors were included), all farm management recommendations were the same across both levels of yield data quality. Therefore, Hypothesis 7 that the same farm management recommendations were made regardless of yield data quality level was not supported when both spatial analysis techniques were considered. However, H7 would have been supported if only the analysis based on a wider spatial interaction structure would have been considered. In this case, data quality was more important when the more common and less computationally intense minimum Euclidean distance spatial interaction structure was used and differences were smaller when the more computationally intense spatial interaction structure was used.

Table 4 Parameter settings for yield monitor data filtering procedure

Field experiment	D1		D2		D3		F1		W1		W2	
Parameter	Value	Deleted obs	Value	Deleted obs	Value	Deleted obs	Value	Deleted obs	Value	Deleted obs	Value	Deleted obs
Maximum velocity (m s^{-1})	3.1	0	1.6	380	1.8	166	2.3	8	3.1	0	3.1	32
Minimum velocity (m s^{-1})	0.9	564	0.7	1,042	0.7	1,847	1.8	1,802	1.6	3,354	1.3	4,291
Smooth velocity (%)	0.15	429	0.1	911	0.1	785	0.2	408	0.2	942	20	1,398
Minimum swath (mm)	NA	NA	NA	NA	5,588	842	NA	NA	3,048	234	3,048	569
Maximum yield (Mg ha^{-1})	15.69	35	5.72	406	6.05	277	5.38	49	17.26	322	17.26	635
Minimum yield (Mg ha^{-1})	0.63	0	0	0	1.01	1,155	0	0	0.94	183	0.31	984
Standard deviation	3	393	4	853	3	1,452	4	1,524	4	1,456	4	1,812
Flow delay (s)	NA	0	−3	511	−3	562	3	561	0	0	2	957
Start pass delay (s)	3	214	4	679	6	1,106	4	745	0	0	0	0
End pass delay (s)	2	214	4	172	4	190	0	0	0	0	0	0

Advice from case study farmers for other farmers

The overwhelming advice from case study farmers for farmers conducting on-farm trials for the first time was to keep the experiments as simple as possible. Farmer W suggested that public sector extension experts should be consulted on choice of experimental design (see Table 2). Farmers F and W stated that farmers need to work with their advisors, including analysts, from the beginning of the project to ensure the experiment is conducted properly and to determine the feasibility of gathering usable data.

Yield monitor calibration was commonly emphasized, with Farmer P re-iterating by saying that one would want to avoid ending up in a "garbage in, garbage out" situation (see Table 2). On-farm trials require more time and effort than production operations. If farmers conduct on-farm trials, they must be willing to pay the cost of gathering quality information (Griffin et al. 2006a). Farmer F stated that extra time must be devoted to plan, implement, harvest and analyze on-farm trial data to reap the benefits. Farmers were advised to share information with one another.

Conclusions

Five case study farmers provided information on their use of yield monitors in conducting on-farm trials. The three farmers who received a spatial analysis report of their on-farm trials along with a production recommendation stated that they were more confident in their data and farm management decisions than before being introduced to spatial analysis, favored split-field designs over strip-trial designs and consistently requested more training in interpretation of statistical results, as well as farm management recommendations that include agronomic and economic analyses. The five field experiments indicated that yield monitor data quality influences the production recommendation. Spatial analysis of yield monitor data may be one example of a need for university extension and agricultural industry to provide education, training, and services to farmers and their advisors.

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